PETRI NET-BASED OPTIMAL ONE-WAFER CYCLIC SCHEDULING OF TREELIKE HYBRID MULTI-CLUSTER TOOLS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/221,038, filed on Sep. 20, 2015, which is incorporated by reference herein in its entirety.

LIST OF ABBREVIATIONS

[0002] BM buffer module
[0003] FP fundamental period
[0004] EST extended sub-tree
[0005] LB lower bound
[0006] O^2CS optimal one-wafer cyclic schedule
[0007] OSLB one-wafer cyclic schedule achieving the LB of cycle time
[0008] PM process module
[0009] PN Petri net
[0010] ST sub-tree

BACKGROUND

Field of the Invention

[0011] The present invention generally relates to scheduling a treelike hybrid multi-cluster tool. In particular, the present invention relates to a method for generating an optimal one-wafer cyclic schedule with minimal cycle time for this multi-cluster tool when no one-wafer cyclic schedule that achieves a LB of cycle time exists.

LIST OF REFERENCES

[0012] There follows a list of references that are occasionally cited in the specification. Each of the disclosures of these references is incorporated by reference herein in its entirety.

[0013] W. K. Chan, J. G. Yi, and S. W. Ding, "On the optimality of one-unit cycle scheduling of multi-cluster tools with single-blade robots," *Proceedings of 2007 IEEE International Conference on Automation Science and Engineering*, pp. 392-397, Scottsdale, USA, 2007.

[0014] W. K. Chan, J. G. Yi, and S. W. Ding, "Optimal Scheduling of Multi-cluster Tools with Constant Robot Moving Times, Part I: Two-Cluster Analysis," *IEEE Transactions on Automation Science and Engineering*, vol. 8, no. 1, pp. 5-16, 2011a.

[0015] W. K. Chan, J. G. Yi, S. W. Ding, and D. Z. Song, "Optimal Scheduling of Multi-cluster Tools with Constant Robot Moving Times, Part II: Tree-Like Topology Configurations," *IEEE Transactions on Automation Science and Engineering*, vol. 8, no. 1, pp. 17-28, 2011b.

[0016] S. W. Ding, J. G. Yi, and M. T. Zhang, "Multicluster Tools Scheduling: an Integrated Event Graph and Network Model Approach," *IEEE Transactions on Semiconductor Manufacturing*, vol. 19, no. 3, pp. 339-351, 2006.

[0017] J.-H. Kim, T.-E. Lee, H.-Y. Lee, and D.-B. Park, "Scheduling analysis of timed-constrained dual-armed cluster tools," *IEEE Transactions on Semiconductor Manufacturing*, vol. 16, no. 3, 521-534, 2003.

[0018] T.-E. Lee, H.-Y. Lee, and Y.-H. Shin, "Workload balancing and scheduling of a single-armed cluster tool," *Proceedings of the 5th APIEMS Conference, Gold Coast, Australia*, pp. 1-15, 2004.

[0019] M.-J. Lopez and S.-C. Wood, "Systems of multiple cluster tools configuration, reliability, and performance," *IEEE Transactions on Semiconductor Manufacturing*, vol. 16, no. 2, pp. 170-178, 2003.

[0020] T. L. Perkinson, R. S. Gyurcsik, and P. K. MacLarty, "Single-wafer cluster tool performance: An analysis of the effects of redundant chambers and revisitations sequences on throughput," *IEEE Transactions on Semiconductor Manufacturing*, vol. 9, no. 3, pp. 384-400, 1996.

[0021] T. L. Perkinson, P. K. MacLarty, R. S. Gyurcsik, and R. K. Cavin, III, "Single-wafer cluster tool performance: An analysis of throughput," *IEEE Transactions on Semiconductor Manufacturing*, vol. 7, no. 3, pp. 369-373, 1994.

[0022] S. Sechi, C. Sriskandarajah, G. Sorger, J. Blazewicz, and W. Kubiak, "Sequencing of parts and robot moves in a robotic cell," *International Journal of Flexible Manufacturing Systems*, vol. 4, no. 3-4, pp. 331-358, 1992.

[0023] S. Venkatesh, R. Davenport, P. Foxhoven, and J. Nulman, "A steady state throughput analysis of cluster tools: Dual-blade versus single-blade robots," *IEEE Transactions on Semiconductor Manufacturing*, vol. 10, no. 4, pp. 418-424, 1997.

[0024] N. Q. Wu, "Necessary and Sufficient Conditions for Deadlock-free Operation in Flexible Manufacturing Systems Using a Colored Petri Net Model," *IEEE Transactions on Systems, Man, and Cybernetics, Part C*, vol. 29, no. 2, pp. 192-204, 1999.

[0025] N. Q. Wu, C. B. Chu, F. Chu, and M. C. Zhou, "A Petri net method for schedulability and scheduling problems in single-arm cluster tools with wafer residency time constraints," *IEEE Transactions on Semiconductor Manufacturing*, vol. 21, no. 2, pp. 224-237, 2008.

[0026] N. Q. Wu, F. Chu, C. Chu, and M. Zhou, "Petri Net-Based Scheduling of Single-Arm Cluster Tools With Reentrant Atomic Layer Deposition Processes," *IEEE Transactions on Automation Science and Engineering*, vol. 8, no. 1, pp. 42-55, January 2011.

[0027] N. Q. Wu, F. Chu, C. B. Chu, and M. C. Zhou, Petri net modeling and cycle time analysis of dual-arm cluster tools with wafer revisiting, *IEEE Transactions on Systems, Man, & Cybernetics: Systems*, vol. 43, no. 1, pp. 196-207, 2013a.

[0028] N. Q. Wu, M. C. Zhou, F. Chu, and C. B. Chu, "A Petri-net-based scheduling strategy for dual-arm cluster tools with wafer revisiting," *IEEE Transactions on Systems, Man, & Cybernetics: Systems*, vol. 43, no. 5, pp. 1182-1194, 2013b.

[0029] N. Q. Wu and M. C. Zhou, "Avoiding deadlock and reducing starvation and blocking in automated manufacturing systems based on a Petri net model," *IEEE Transactions on Robotics* and Automation, vol. 17, no. 5, pp. 658-669, 2001.

[0030] N. Q. Wu and M. C. Zhou, *System modeling and control with resource-oriented Petri nets*, CRC Press, Taylor & Francis Group, New York, October 2009.

[0031] N. Q. Wu and M. C. Zhou, "Analysis of wafer sojourn time in dual-arm cluster tools with residency time